1 Momentum conservation

In order to understand the nature of the near- and away-side correlation pattern for events with a (moderately) high transverse momentum (p_T) trigger hadron on the near side, it is useful to look at momentum conservation first. Clearly, there is a fundamental difference between near- and away side: The trigger hadron momentum on the near side must be balanced somehow on the away side since the initial state has no transverse momentum. Therefore an away side correlation *must* appear because of momentum conservation, a near side correlation *may* appear due to other physics — if it does, its momentum must be balanced on the away side as well.

To first order, the away side correlation thus reflects momentum conservation. The interesting physics is then contained in the nature of the momentum conserving process, in other words in the distribution of the momentum flow across different particles in p_T, angle ϕ and rapidity η. In a hard event, initially two back-to-back partons balance the momentum. In the absence of a medium, this leads to a hard, jet-like correlation on the away side with relatively narrow width in ϕ, corresponding to hadronization of the away side parton into a hadron shower. However, in the presence of a medium, several observations suggest that here the correlation is not created by medium-modified fragmentation of a parton but rather by the bulk recoil of the medium, among them the p_T spectrum of the correlation and its hadrochemistry which both agree well with bulk properties but not with jet properties. This strongly disfavours explanations like jet deflection or Cherenkov radiation and points rather to some generic shockwave response of a medium characterized by collectivity.

2 What makes the observed angle constant?

One common class of models explains the away side correlation as a Mach cone — soundwaves excited by a parton travelling supersonically through the medium. This explanation has the advantage that it can explain naturally why the correlation is seen with bulk properties and why the correlation angle shows no change as a function of rapidity (as sound couples to longitudinal flow and the correlation is elongated in rapidity). If so, the observed angle would reflect the average speed of sound in the medium. However, several things need to be considered before drawing such a conclusion. First, a Mach cone is a complicated phenomenon which in addition to the actual cone also involves for example a diffusion wake and a 'neck' region close to the source, both of which would lead to correlation strength at an angle different from the Mach angle. Second, viscosity (or more precisely a large value of η/s) would quickly dampen a soundwave. Third, the cone would be distorted by transverse flow, and finally the signal would need to survive hadronization and freeze-out.

In the light of the above, the observation that the correlation angle does not change even at low SPS energies is very interesting. Clearly, one can not assume an almost perfect fluid at such low energies where hydrodynamics is known to fail the reproduce the elliptic flow v_2. However, such a constant angle can be understood as arising from multiple bias effects.

First, in the presence of medium-induced energy loss, there is surface bias for the hard vertex. Partons produced in the center of the medium are less likely to escape and thus to become a trigger than partons produced close to the near side surface. This is found universally in jet quenching models, and measurements of the angular dependence of single hadron and dihadron suppression support this picture. This however implies that despite substantial changes in the central temperature of the medium from lower SPS to RHIC energy, the surface region into which the away side parton is typically placed is rather similar in all systems. Moreover, since hydrodynamics creates radial flow with a specific position-momentum correlation and radial flow is not very different from SPS to RHIC, the implication is that the away side parton is also produced typically with s specific orientation with respect to flow with given strength.

This naturally leads to the alignment bias: The correlation is dominated by events in which shockwave propagation and radial flow are aligned (this can be understood e.g. from the Cooper-Frye formula). Events in which the directions are not aligned on the other hand cause a much weaker and more diffuse correlation pattern which averages out. Thus, the combination of surface bias, position-momentum correlation of flow and alignment bias naturally favours particular angles, quite independent on the actual angle relevant for the shockwave.

A third effect has to do with the fact how theoretical calculations are often compared with the data. If the away side parton (as often done) is assumed to be at midrapidity ($\eta = 0$) then any correlation with a small angle with respect to this parton will be completely inside the detector acceptance in rapidity whereas any large angle correlation will only be partially inside the acceptance. However, if the unknown position of the away side parton (which can be computed in pQCD) is properly averaged over, the small angle part of the correlation is moved out of the acceptance whereas roughly the same fraction of a large angle correlation remains inside. In essence, this effect tends to create a dip at small angles, even for calculations which would not show a dip for the away side parton at midrapidity.

There is thus a rather generic dynamical picture which tends to create correlations at the same angle for a wide range of shockwave (and related) scenarios. The picture breaks down only if the assumptions about the medium recoil become too extreme. It does not require an ideal fluid or a well-defined cone but would work equally well for a bulk response of a medium showing some degree of collectivity, provided there is some mechanism to transport momentum to large ϕ. Thus, the current data can not be taken as supportive of a particular scenario, nor can they be used to extract medium properties like the speed of sound of η/s, as the generic dynamics outlined above to first order erases all properties of the original shockwave.

3 The ridge

Turning to the ridge correlation, observations suggest that it is not related to energy loss of a trigger hadron. Not only is a ridge correlation measured without a trigger, but connecting it to energy loss poses severe problems.

If one assumes that the ridge is a recoil of the bulk medium as a response to near side energy loss, then the fact that the ridge is observed up to 4 units in η does not connect with energy loss taking place rather late (2-4 fm/c) without a violation of causality. At late times, there is no chance to correlate regions so far apart in spacetime rapidity. On the other hand, energy being lost late is due to a coherence time effect and thus a generic property of quantum field theories and as such unavoidable.

One may try to get around this by proposing that the ridge is built by radiation (and by chance has a hadrochemistry comparable to that of the medium). Since the momentum rapidity rather than the spacetime rapidity of particles is measured, radiated gluons could in principle be at 4 units of rapidity while being at a smaller spacetime rapidity, thus there is no causality violation. However, the energy lost from the near side parton is constrained by the nuclear suppression R_{AA}. The limit here is $\sim$ 4 GeV, however a more realistic number as obtained in detailed jet quenching calculations is $\sim$0.5 GeV. This is not enough energy to radiate substantially into 4 units of rapidity.

Thus, it is very likely that the ridge correlation is connected with an initial state effect which creates long correlations in $\Delta\eta$, possibly Glasma flux tubes, and that the correlation with a trigger is rather accidential. One possible mechanism which could correlate trigger hadrons and the ridge is the fact that both the direction of partons escaping from the medium and the radial flow which would boost flux tubes are perpendicular to the medium surface. Note that this effect would go away if one triggers on a dihadron, as a dihadron is not emitted preferentially perpendicular to the surface, and indeed for dihadron triggered events no ridge is seen.